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Final Technical Report: NASA Grant NAGW-1163

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May 1994

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This grant supported research into uses of the *Hubble Space Telescope* Guide Star Selection System data base for important astrophysical problems ancillary to HST observations. The initial focus was to use the data to survey the frequency of wide binary stars at high galactic latitude, as a probe of local dark matter. In the course of this work, it was also discovered that the data base could be used for a purpose never envisaged by its designers, namely, detection of proper motions in faint stars. Some further evaluation of this capability supported by the grant led to the discovery of an entirely new class of stellar object, namely the dwarf carbon star.

Publications supported by this grant, including both papers in refereed journals, and also two Ph.D. thesis dissertations, are described briefly below in chronological order of appearance. Each of these publications acknowledges the financial support of this grant.

"Wide binary stars at the Galactic poles," P. J. Garnavich, ApJ, 335, L47, 1988.

Wide binary stars are weakly bound systems easily disrupted by encounters with the constituents of the Galaxy. Thus, they provide a unique way to probe the dynamics and mass distribution of the Galactic disk. Five samples of stars complete to visual magnitude 14.0 and covering a total of 110 deg^2 near the Galactic poles are used to search for wide binary stars. The estimated number of binaries in the total sample is three times smaller than that expected from the study by Bahcall and Soneira (1981). The pair separation distribution is compared with a model of wide binary properties using a technique developed by Wasserman and Weinberg (1987). The wide binary density derived from the model is

also three times smaller than that found in the earlier study, but remains unphysically large. The Wasserman-Weinberg model predicts that wide binaries should be found in the faint half of the sample ($m_v > 12$), but none are detected.

"Three Newly Recognized Dwarf Carbon Stars", P. J. Green, B. Margon, and D. J. MacConnell, ApJ, 380, L31, 1991.

The identification is confirmed of two faint high-latitude carbon stars with previously catalogued high proper motion objects. The discovery of proper motion is reported in a third. The R=15.5 star CLS 96 corresponds to LP 328-57, with $\mu = 0.28''$ yr^{-1}, and C*22 (Bothun et al.) is LP765-18=LHS 1075, with R=14 and $\mu = 0.62''$ yr^{-1}. In addition, CLS 31, with R=16.5, is found to have $\mu = 0.13''$ yr^{-1}. These three objects are thus inferred to be dwarf carbon stars, supplementing the one previously known case. All of these objects have JHK colors similar to the prototype dwarf C star, G77-61, suggesting IR colors as a useful luminosity indicator. LP 328-57 and G77-61 also share certain spectral peculiarities. Both LP 328-57 and LHS 1075 are probably at distances of approximately 100 pc and may have detectable parallaxes.

"The Stellar Angular Correlation Function: Clues to Wide Binary Star Properties," P. J. Garnavich, Ph.D. dissertation, University of Washington, 1991.

The angular distribution of stars brighter than visual magnitude 14 is analyzed for evidence of gravitationally bound systems with widely separated components. Binary stars with separations on the order of 0.1 pc are interesting as probes of Galactic dynamics, disk dark matter, the Oort comet cloud and the postulated Solar companion star, Nemesis.

Catalogs of stars, complete to a resolution limit of $4''$, were constructed from digitized Schmidt telescope plates covering over 600 deg^2 of the sky in four directions. The clustering properties of stars and star pairs are analyzed using two-point and three-point angular correlation functions. Significant correlation (assumed to be due to binary stars) is detected only for angular separations less than $40''$. No significant numbers of ternary systems are detected.

Employing a modified Wasserman-Weinberg technique, the angular correlation functions are directly compared with a simple model of wide binary star properties. The wide binary semimajor axis distribution at low Galactic latitudes is best described as a single power law of index -1.3. Near the north Galactic pole (NGP), the power law is less steep and

the distribution is consistent with a cutoff near 0.1 pc. The derived wide binary density is unrealistically large, suggesting that the basic model inadequately characterizes wide binary properties.

A sample of stars from the Space Telescope Guide Star Catalog (GSC) has also been studied. The region analyzed lies within thirty degrees of the NGP and covers 2500 deg^2 of sky. This large, low resolution sample complements the smaller, more uniform plate catalogs. Many systematic errors in the GSC are identified, and an attempt is made to account for image misclassifications and poorly defined resolution limits. The corrected stellar correlation function from the GSC is found to be consistent with a wide binary separation cutoff near 0.1 pc.

The dissolution of a poor Galactic cluster at the NGP may explain the observed wide binary distribution in that direction. Evidence for weak clustering on scales of one degree is seen in the pair-pair correlation function.

The unphysically large wide binary density derived from magnitude-limited samples is explained well by a luminosity correlation between the binary components. An alternative solution requires all F to K dwarfs to be members of wide binaries. Based on the observed properties of wide binary stars, the probability that the Sun has a stellar companion capable of inducing periodic mass extinctions on Earth is only 0.05%. In an analogy with Oort cloud dynamics, a mechanism is suggested that can substantially reduce the number wide binaries with separations greater than 0.1 pc.

"Faint High Latitude Carbon Stars," P. J. Green, Ph.D. dissertation, University of Washington.

A wide area survey to search for faint high latitude carbon (FHLC) stars has been undertaken. Carbon giants are ideal for study of the structure and kinematics of the outer galactic halo. We use two color photometric selection with large format charge-coupled devices (CCDs) to cover 52 deg^2 of sky to a depth of about $V = 18$. Below this limit, we find good ($\lesssim 20\%$) agreement between our object counts as a function of magnitude and the galactic models of Bahcall & Soneira (1984) at a variety of latitudes and longitudes.

Our spectroscopic followup began with low-resolution spectra of 19 unconfirmed C star candidates from the Case objective-prism photographic survey of Sanduleak and Pesch (1988). Four of these we find to be M stars. The 15 C stars we classify on the two-parameter Keenan-Morgan (1941) system as warm (color class < 4), with moderate to weak carbon band strengths (C class < 3). Of 94 faint C star candidates from our own CCD survey,

one highly ranked $V = 17$ candidate was found to have strong carbon and CN bands. We estimate that to a depth of $V = 18$, the surface density FHLC stars is $0.019^{+0.044}_{-.016}\mathrm{deg}^{-2}$.

We identify two FHLC stars with previously catalogued high proper motion objects. These objects are thus inferred to be dwarf carbon (dC) stars, supplementing the one previously known case, G77-61. Not all dC stars will have detectable proper motions, so other luminosity/distance indicators are needed: we find that C dwarfs all have similar JHK colors, and possibly an unusually strong λ6191 bandhead of carbon. By comparing positions in the HST Guide Star Catalog and the original Palomar Observatory Sky Survey, we detect proper motions in two additional FHLC stars. Our proper motion survey, spanning a 30 year baseline, thus identifies two new dCs, and provides proper motion upper limits for another 44 FHLC stars. Kinematic simulations suggest that virtually all Population II dCs will have detectable proper motions in a survey as sensitive as our own, and that to a limit of $V \approx 18$, at least 10% of FHLC stars are dwarfs. The local space density of dC stars may thus substantially exceed that of luminous C stars, so that the automatic assumption of giant luminosities for C stars is no longer valid.

"Carbon Star Luminosity Indicators", P. J. Green, B. Margon, S. F. Anderson, and D. J. MacConnell, ApJ, 400, 659, 1992.

Except for one odd dwarf, G77-61, it has long been assumed that carbon (C) stars are always giants. However, the existence of high proper motions has been confirmed in three other faint C stars. These three C stars are thus also inferred to be dwarfs. C dwarfs have similar JHK colors, suggesting IR colors as a possible luminosity indicator. An unusually strong λ6191 bandhead of carbon is found in the spectra of the dwarf C stars known to date. We present results of a proper motion survey of known faint high-latitude C stars using plates spanning a 30 yr baseline, that reveals at least one additional new dwarf C star and also confirms the utility of proposed luminosity indicators. Kinematic simulations suggest that virtually all Population II C dwarfs will have detectable proper motions, and that to a limit of $V \sim 18$, at least 10% of faint high-latitude C stars are dwarfs. The local space density of dwarf C stars may thus substantially exceed that of luminous C stars.